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Relative Economic Profitability of Millet based Crop Rotations with Chickpea in Hisar District of Haryana

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ABSTRACT

Background: Millets and pulses are the most important dryland crops grown in both *Kharif* and *Rabi* seasons in the semi-arid regions of the country for food, feed and animal fodder. These crops also show considerable resilience to changing climate (drought, heat and nutrient stresses). For diversification of Pearl millet-Chickpea rotation, adoption of small millets (finger millet, foxtail millet, proso millet, little millet, brown top millet, barnyard millet and kodo millet) in addition to pearl millet may be viable option.

Methods: A field experiment was carried out at CCS Haryana Agricultural University, Hisar, Haryana, India during 2022-23 in randomized block design in *Kharif* and *Rabi* season, replicated thrice with eight treatments (foxtail millet, little millet, brown top millet, proso millet, kodo millet, barnyard millet, finger millet and pearl millet) in *Kharif* season and eight crop rotations (foxtail millet-chickpea, little millet-chickpea, brown top millet-chickpea, proso millet-chickpea, kodo millet-chickpea, barnyard millet-chickpea, finger millet-chickpea and pearl millet-chickpea) in *Rabi* season to evaluate economic profitability of eight millet based crop rotations with chickpea.

Result: During *Kharif* season among all millets (foxtail millet, little millet, brown top millet, proso millet, kodo millet, barnyard millet, finger millet and pearl millet) tested, Pearl millet was found most suitable, which produced significantly higher grain yield (2462 kg/ha), biological yield (10066 kg/ha), net energy returns (121552 MJ/ha), energy intensiveness (14.0 MJ/USD), human energy profitability (133.3 MJ/ha) compared to all other millets. In *Rabi* season chickpea sown after Foxtail millet recorded significantly higher seed yield (2080 kg/ha), biological yield (8923 kg/ha), net returns (Rs. 66713/ha), B:C (2.44), net energy returns (120497 MJ/ha), energy ratio (19.27), energy productivity (0.31 kg/MJ), energy profitability (18.27 MJ/ha) and human energy profitability (134.2 MJ/ha).

Key words: Chickpea, Economics, Energy budgeting, Millets, Yield.

INTRODUCTION

Haryana ranks second as a food grains contributor to the nation's food basket with it's nearly 70 per cent of the population engaged in agriculture had a rich legacy of sustainable agricultural development witnessing an production of 2.6 MT in 1966-67 to 18.3 MT in 2020-21 food-grain with eleven-fold increases in wheat and sixteen-fold increase in rice production during this period (Anonymous, 2022). The common cropping systems practiced in irrigated Northern and Central Haryana isrice-wheat, while in Southern Haryana cotton-wheat, pearl millet-chickpea and pearl millet-mustard cropping system are very common. But after continuous cropping, these allcrop rotations are facing new challenges like yield stagnation, resources depletion and deterioration, pest pressure, nutrient mining and burning of crop residue, which put questions on the sustainability of all these cropping systems in Haryana (Patel *et al.,* 2023; Sammauria *et al.,* 2020). From resource conservation and sustainability point of view most successful and highly adopted crop rotation in the dry regions of south Haryana is pearl millet-chickpea cropping system. So, now most of these systems require diversification for greater sustainability, better economics and conservation of natural resources. Crop diversification, defined as the introduction or addition of new crops to the existing farming system, can occur at the individual farm level or at larger scales. It can be one of the most ecologically feasible, cost-effective and rational ways of reducing uncertainties in agriculture-especially among small holder farmers (Kumar *et al.,* 2023; Yadav *et al.,* 2017).

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Millets and pulses have potential to grow in harsh environment and minimize risks of entire crop failure unlike other cereals namely, wheat, rice and maize (Sivagamy *et al.,* 2024). Millets and pulses, in India, bear significant relevance in promoting food and nutritional security for a number of reasons. These are the staple source of protein to a significant share of the Indian population and in particular the vegetarian population. They are also a rich source of fibre, vitamins and minerals, such as iron, zinc, folate and magnesium (Divya and Garg, 2024; Sandhya *et al.,* 2022). Just as pulses provide nutritional benefits to humans, they also produce a number of different compounds that feed soil microbes thus benefitting soil health. One of the most popular benefits is the ability of pulses to fix atmospheric nitrogen (N) thereby, improving soil fertility (Kamal *et al.,* 2023; Kamal *et al.,* 2024). Not only do pulses discharge greater and different types of amino acids, the plant residues left after harvesting pulse crops also improve biochemical composition of the soil. Hence, pulses production can be provided compatibility with cereal crops to promote sustainability of the farming systems (Kumar *et al.,* 2023; Lal, 2017; Sharma *et al.,* 2023).

Millets and pulses are the most important dryland crops grown in both *Kharif* and *Rabi* seasons in the semi-arid regions of the country for food, feed and animal fodder. These crops also show considerable resilience to changing climate (drought, heat and nutrient stresses) (Singh *et al.,* 2023; Hemalatha *et al.,* 2021; Bandyopadhyay *et al.,* 2017; Habiyaremye *et al.,* 2017). Pearl millet is one of the important rainfed food grain crop of the arid and semi-arid region (Faiz *et al.,* 2022; Meena *et al.,* 2021; Kumar *et al.,* 2016). It forms a staple cereal in the diets of millions of farmers inhabiting these regions. Chickpea (*Cicer arietinum* L.) is the major *rabi* pulse crop grown in rainfed black soil tracts of India. In worldwide, India occupies first position in terms of production and consumption with nearly 75 per cent of the world cultivated area (Dhaka *et al.,* 2024).

For diversification of Pearl millet-Chickpea rotation, adoption of small millets (finger millet, foxtail millet, proso millet, little millet, brown top millet, barnyard millet and kodo millet) in addition to pearl millet may be viable option (Habiyaremye *et al.,* 2017). There is an immediate need to promote the cultivation of millets to ensure food and nutritional security at national level because small millets are considered climate smart and nature friendly crops because of high nutritive value, tolerance to water and temperatures stress, short life, low external inputs requirement (Jeeva *et al.,* 2024; Dhaka *et al.,* 2023). Farmers need to be continuously motivated and encouraged to pursue crop diversification for better sustainability as well as income and employment opportunities (Sammauria *et al.,* 2020). Considering the importance of millets in food and nutritional security, the year 2018 as ‘National Year of Millets’ at national level and the year 2023 as ‘International Year of Millets’ was celebrated at global level. Millets are currently grown in 131 countries in over 78 million ha with sorghum and pearl millet accounting for over 90 per cent share at global level (Singh *et al.,* 2023). India is the largest grower (with 19% contribution) and producer (20% production) of millets in the world (Dhaka *et al.,* 2023a). The most important states for pearl millet cultivation are Rajasthan, Uttar Pradesh and Maharashtra having a total share of 78 per cent (Bhuva and Detroja, 2018). Karnataka alone accounts for more than $2/3^{rd}$ acreage of finger millet. Chhattisgarh and Madhya Pradesh grow more than 60 per cent of small millets. All efforts made by Government to promote millets have been responded well by farmers and consumers. But very limited research work has been conducted so far on different minor millet-based crop rotations with chickpea except Pearl millet- Chickpea crop rotation. So, considering all these facts mentioned above a field experiment was conducted at CCS Haryana Agricultural University, Hisar, Haryana, India to study the relative economic profitability of eight millet based crop rotations with chickpea.

MATERIALS AND METHODS

A field experiment was carried out at crop physiology field research area of CCS Haryana Agricultural University, Hisar, Haryana, India (29°10′N latitude, 75°46′E longitude and 215.2 M altitude) during 2022-23 in randomized block design in *Kharif* and *Rabi* season, replicated thrice with eight treatments (foxtail millet, little millet, brown top millet, proso millet, kodo millet, barnyard millet, finger millet and pearl millet) in *Kharif* season and eight crop rotations (foxtail millet-chickpea, little millet-chickpea, brown top millet-chickpea, proso millet- chickpea, kodo millet-chickpea, barnyard millet-chickpea, finger millet-chickpea and pearl millet-chickpea) in *Rabi* season to evaluate economic profitability of eight millet based crop rotations with chickpea. Soil of the field was sandy loam in texture, slightly alkaline in pH (7.6), low organic carbon, poor in available phosphorus, medium in available nitrogen and rich in available potassium. The maximum and minimum temperature during the crop study period was congenial for the growth and development of crops. Sowing of all millets *viz.* Foxtail millet (SIA 3156), Little millet (DHLM 36-3), Brown top millet (IIMR AK 2), Proso millet (TNAU 202), Kodo millet (JK 41), Barnyard millet (VC 27), Finger millet (GPU 67) and Pearl millet (HHB 67) in *Kharif* season was done on 27th July, 2022 and these were harvested at 78, 92, 73, 69, 91, 78, 116 and 71 days after sowing, respectively. Agronomical management for each millet was done separately as per the recommendations given by Indian institute of millets research, hyderabad. During *Rabi* season, all millets were followed by chickpea (HC 7). The sowing of chickpea was done on 20th October, 2022 after Foxtail millet, Brown top millet, Proso millet, Barnyard millet and Pearl millet while after Little millet and Kodo millet it was sown on 27th October, 2022 and after Finger millet chickpea was sown on 29th November, 2022. Chickpea was harvested at 164 days in case of Foxtail millet, Brown top millet, Proso millet, Barnyard millet and Pearl millet, while after Little millet and Kodo millet chickpea was harvested at 157 days after sowing. Minimum days (124) up to harvesting were taken by chickpea in case of finger millet. Treatment wise chickpea was fertilized with recommended dose of nutrients (20 N+40 P_2O_5 kg/ha) and inputs were given as per the recommendations of CCS haryana agricultural university, hisar. The energy equivalents of all inputs in the form of labour, seeds, fertilizers, hoeing, implements and pesticides and the energy output as produce was converted into energy (MJ) to calculated input and output energy of both crop seasons as well as crop rotation as per conversion factors as given by Kumar *et al.* (2022); Dhaka *et al.* (2017) and Net energy return was calculated as difference between the total output energy and total input energy. Energy ratio was determined as energy output divided by input energy. Human energy profitability was calculated by dividing output energy with labour energy. Energy productivity was calculated by dividing the seed yield of crop by their respective input energy requirement. Energy intensiveness was expressed as total input energy divided by cost of cultivation. Energy profitability was computed by dividing the Net energy return with total input energy. Specific energy was calculated by Input energy divided by grain yield in kg/ha.

To compute the relative economics of all crop rotations, the data provided by Department Agriculture Economics, CCS Haryana Agricultural university, Hisar was considered for both season crop's inputs and outputs. The price considered for grains of Foxtail millet, Little millet/ Brown top millet/Proso millet, Kodo millet, Barnyard millet, Finger millet and Pearl millet was Rs. 2909, 2300, 2599, 2800, 3578 and 2350 per quintal, respectively, while straw rate was Rs. 1500/acre. The price used for chickpea seed and straw were Rs. 5230/qt and Rs.1558/acre. The total and variable cost, gross and net returns, B:C and per day returns for all eight crop rotations were calculated.

RESULTS AND DISCUSSION

Kharif season

Table 1 cleared that yield attributes and yield was significantly affected by millets. Among millets Pearl millet and Kodo millet recorded significantly higher (190.5 cm) and lower (89.1 cm) plant height, respectively. Foxtail millet, Little millet, Brown top millet and Barnyard millet recorded plant height within range of 156.1-167.3 cm with non significant variation among themselves. Little millet followed by Proso millet and Kodo millet followed by Finger millet recorded significantly higher (29.6-28.6 cm) and lower (5.6-7.1 cm) ear head length, respectively. Brown top millet (17.5 cm) and Barnyard millet (18.6 cm), Foxtail millet (20.3 cm) and Pearl millet (20.0 cm) recorded statistically similar ear head length. Significantly higher total tillers (86.5), ear heads (77.3) and lower total tillers (9.3), ear heads (8.3) per plants were recorded with Proso millet and Finger millet, respectively. Foxtail millet, Kodo millet and Barnyard millet had shown non-significant variation regarding total tillers and ear heads per plant. Pearl millet followed by Barnyard millet and Little millet followed by Brown top millet recorded significantly higher (81.8 g) and lower (13.5 g) ear heads weights per plant, respectively. Among millets, pearl millet followed by finger millet and barnyard millet recorded significantly higher grain yield (2462 kg/ha), straw yield (7604 kg/ha) and biological yield (10066 kg/ha), while significantly lower grain yield (761 kg/ha), straw yield (3076 kg/ha) and biological yield (4117 kg/ha) were recorded with Little millet, Foxtail millet and Kodo millet, respectively. Little millet, Proso millet and Kodo millets had shown non-significant differences regarding yield performance. Foxtail millet closely followed by Brown top millet and Pearl millet recorded significantly higher harvest index (30.2%), while Little millet recorded significantly lower harvest index (17.9%). Except Foxtail millet and Brown top millet all millets had shown non-significant variations regarding harvest index compared to Little millet. Pearl millet followed by Kodo millet and Little

Table 1: Comparative yield performance of millets in Hisar district of Haryana.

Millets	Yield attributes per plant						Yield per hectare area				
	Plant height	Ear head length (cm)	Tillers (nos.) (cm)	Ear heads (nos.)	Ear heads weight (g)	Seed weight (g)	Seed yield (kg/ha)	Biological yield (kg/ha)	Straw yield (kg/ha)	HI (%)	Test weight (g)
Foxtail millet	156.1	20.3	16.5	15.5	40.8	31.2	1,347	4,424	3,076	30.2	2.58
Little millet	166.3	29.6	27.8	18.0	13.5	9.5	761	4,280	3,518	17.9	1.94
Browntop millet	167.3	17.5	25.6	20.1	15.2	10.9	1,571	5,985	4,414	26.2	3.37
Proso millet	120.3	28.6	86.5	77.3	25.8	9.2	930	4,190	3,260	22.4	4.40
Kodo millet	89.1	5.6	19.5	16.1	20.2	14.3	816	4,117	3,301	20.6	4.87
Barnyard millet	159.5	18.6	18.6	14.0	56.3	37.2	1,618	7,805	6,186	20.7	3.29
Finger millet	112.1	7.1	9.3	8.3	30.9	24.3	1,971	9,479	7,507	20.8	3.29
Pearl millet	190.5	20.0	14.0	10.8	81.8	52.7	2,462	10,066	7,604	24.4	6.73
SEm±	5.1	0.6	1.6	1.8	1.6	1.4	125	224	234	2.3	0.10
CD (p=.005)	15.8	1.9	5.0	5.5	5.0	4.3	383	687	717	7.0	0.32

millet followed by Foxtail millet observed with significantly higher (6.73 g) and lower (1.94 g) test weight, respectively. Corroborative findings have also been reported by Garg *et al.* (2020). The increase in grain yield of some millets might be due to increased photosynthetic activity, which resulted in a higher accumulation of photosynthates and their translocation to sink due to better source and sink channel (Krishna *et al.,* 2020; Reddy *et al.,* 2020). The increase in grain yield could be explained based on their beneficial effects on yield-attributing characteristics (Hemalatha *et al.,* 2021). Nalini *et al.* (2020) in a study on pearl millet, Hemalatha *et al.* (2021) in a study on kodo millet, Krishna *et al.* (2020) in a study on finger millet and Reddy *et al.* (2020) in a study on foxtail millet have also reported similar findings. Higher HI in selected millet germplasms might be due to dry matter partitioning along with an increased level of nitrogen as reported by Reddy *et al.* (2016).

Among millets, Finger millet and Proso millet took maximum (116) and minimum (69) days to mature. Brown top millet, Proso millet and Pearl millet took almost similar days up to maturity (69-73 days). Foxtail millet and Barnyard millet were matured in 78 days, while Little millet and Kodo millet took 91-92 days for maturity (Table 2). Table 2 showed that among millets, Finger millet followed by pearl millet recorded maximum variable cost (Rs. 32523/ha), total cost (Rs. 62153/ha), while Foxtail millet recorded minimum variable cost (Rs. 22958/ha) and total cost (Rs. 50675/ha). All millets except finger millet and pearl millet recorded with variable cost Rs. 22958 to 25885/ha and total cost Rs. 50675 to 54188/ha. Finger millet found with significantly higher gross returns (Rs.74128/ha) and net returns (Rs. 11975/ha), which were 20.3 and 176.7 per cent higher compared to pearl millet, respectively. Significantly lower gross returns (Rs. 21273/ha) and net returns (Rs.-29808/ha) were recorded with Little millet. All millets except Finger millet and Pearl millet had shown negative net returns and less than one BC ratio. Finger millet recorded significantly higher B:C (1.19) closely followed by pearl millet (1.07). Similarly maximum per day net returns was recorded with Finger millet (Rs. 103.2/day/ha) closely followed by pearl millet (Rs. 60.9/day/ha). Proso millet recorded minimum net returns per day basis (Rs. 401.6/day/ha). These results are in close conformity with the findings of Bana *et al.* (2016); Bhavani *et al.* (2021); Kumar *et al.* (2009); Garg *et al.* (2020); Krishna *et al.* (2020); Reddy *et al.* (2020).

Table 3 revealed that energy budget in the form of different energy based indices was significantly affected by millets. Among all millets, pearl millet followed by finger

Table 2: Comparative economics of different millets in hisar district of Haryana.

Treatments	Total duration (days)	Variable cost (Rs/ha)	Total cost (Rs/ha)	Gross returns (Rs/ha)	Net returns (Rs/ha)	B:C ratio	Per day return (Rs/day/ha)
Foxtail millet	78	22958	50675	42,953	-7,721	0.84	-98.9
Little millet	92	23298	51083	21,273	-29,808	0.41	-324.0
Browntop millet	73	25885	54188	39,892	-14,294	0.73	-195.8
Proso millet	69	24780	52863	25,147	-27,714	0.47	-401.6
Kodo millet	91	23168	50928	24,895	-26,032	0.48	-286.0
Barnyard millet	78	24473	52495	49,072	-3,422	0.93	-43.8
Finger millet	116	32523	62153	74,128	11,975	1.19	103.2
Pearl millet	71	28463	57280	61,607	4,327	1.07	60.9
SEm±	2.1	-	-	3,274	3,274	0.06	42.4
CD (p=.005)	6.7	-	-	10,029	10,029	0.19	130.0

Table 3: Energy budgeting of different millets in Hisar district of Haryana.

Treatments	Input energy (MJ/ha)	Output energy (MJ/ha)	Net energy returns (MJ/ha)	Energy ratio	Energy productivity (Kg/MJ)	Energy profitability (MJ/ha)	Energy intensiveness (MJ/USD)	Specific energy (MJ/kg)	Human energy profitability (MJ/ha)
Foxtail millet	6758	58264	51506	8.6	0.19	7.6	11.0	5.21	59.2
Little millet	6746	55180	48433	8.1	0.11	7.1	10.9	8.96	56.0
Browntop millet	6729	78277	71548	11.6	0.23	10.6	10.3	4.44	79.5
Proso millet	6946	54427	47480	7.8	0.13	6.8	10.9	7.47	55.3
Kodo millet	6758	53266	46508	7.9	0.12	6.9	11.0	8.34	54.1
Barnyard millet	6758	101123	94365	14.9	0.24	14.0	10.6	4.24	102.7
Finger millet	7420	122824	115403	16.5	0.27	15.5	9.9	3.76	124.8
Pearl millet	9697	131249	121552	13.5	0.25	12.5	14.0	3.94	133.3
SEm±	2.4	2872	2872	0.4	0.02	0.42	0.004	0.53	2.92
CD (p=.005)	7.5	8797	8798	1.3	0.06	1.28	0.013	1.62	8.94

millet recorded significantly higher input energy (9697 MJ/ha), Output energy (131249 MJ/ha), net energy returns (121552 MJ/ha), energy intensiveness (14.0 MJ/USD) and human energy profitability (133.3 MJ/ha), while higher energy ratio (16.5), energy productivity (0.27 kg/MJ) and energy profitability (15.5 MJ/ha) were recorded with finger millet. Kodo millet closely followed by proso millet and little millet observed with lower output energy (131249 MJ/ha), net energy returns (46508 MJ/ha) and human energy profitability (54.1 MJ/ha).

Rabi season

Table 4 cleared that yield attributes and yield of chickpea were significantly affected by previous millet crops. Among all treatments, the chickpea sown over Pearl millet recorded significantly higher plant height (91.3 cm), while shortest plants (55.7 cm) were recorded when chickpea was taken after Finger millet. Chickpea recorded statistical similar plant height (86.6-91.3 cm) when it was taken after Foxtail millet, Proso millet and Pearl millet. Chickpea sown after Brown top millet and Barnyard millet recorded almost similar plant height. Chickpea sown after Foxtail millet followed by Pearl millet- chickpea recorded significant higher number of branches (11.1), while chickpea sown over finger millet recorded significantly lower branches/ plant (6.0) but it was statistically at par with all treatments except Foxtail millet/Pearl millet- chickpea rotation. Significantly higher (1.16) and lower (0.72) seeds/pod were noticed with chickpea sown after Foxtail millet and Pearl millet/Barnyard millet, respectively. Chickpea pod length was non significantly varied among all crop rotations. Chickpea preceded by foxtail millet closely followed by Pearl millet- chickpea rotation recorded significantly higher pods/ plant (122.8), while Chickpea taken after Finger millet recorded significantly lower (73.7) pods/plant. Chickpea sown after Little millet, Proso millet, Kodo millet and Finger millet recorded statistically similar pods/plant. Regarding seed index all treatments had shown non significant differences except chickpea sown after Kodo millet/Finger millet. Significantly higher (15.9 g) and lower (13.7 g) seed index was recorded when chickpea was preceded by Pearl millet millet/Foxtail millet and Finger millet, respectively. Chickpea preceded by foxtail millet closely followed by Pearl millet-Chickpea recorded significantly higher seed yield (2380 kg/ha) and biological yield (8923 kg/ha), while chickpea sown after Finger millet recorded significantly

Table 4: Effect of millets and nitrogen levels on yield attributes and yield of chickpea.

Treatments	Chickpea								
	Plant height (cm)	Branches/ plant (nos.)	Seeds/ pod (nos.)	Pod length (cm)	Pos/plant (nos.)	100 seed weight (g)	Biological yield (kg/ha)	Seed yield (kg/ha)	Harvest index (%)
Foxtail millet	86.8	11.1	1.16	1.47	122.8	15.9	8923	2080	23.4
Little millet	74.3	6.6	1.06	1.48	80.4	15.5	6473	1396	21.4
Browntop millet	82.5	6.5	1.07	1.52	95.0	15.7	8086	1555	19.3
Proso millet	86.6	7.1	1.06	1.47	86.8	15.8	8179	1746	21.2
Kodo millet	74.7	6.5	1.03	1.38	76.4	14.9	4266	1343	31.3
Barnyard millet	82.1	6.6	1.10	1.55	97.2	15.7	8078	1970	24.2
Finger millet	55.7	6.0	0.72	1.21	73.7	13.7	3638	1111	30.4
Pearl millet	91.3	10.4	1.10	1.52	117.6	15.9	8588	2008	23.3
SEm±	1.80	0.6	0.04	0.07	4.9	0.32	330	128	3.10
CD (p=.005)	5.52	2.0	0.14	NS	15.1	0.99	1010	393	9.50

Table 5: Effect of millets and nitrogen levels on economics of chickpea.

Treatments	Total duration (days)	Variable cost (Rs/ha)	Total cost (Rs/ha)	Gross return (Rs/ha)	Net returns (Rs/ha)	B:C	Per day return (Rs/day/ha)
Foxtail millet	160	29050	46270	112983	66713	2.44	416
Little millet	157	29050	46270	76924	30654	1.66	194
Browntop millet	162	29050	46270	85209	38939	1.84	238
Proso millet	162	29050	46270	95185	48915	2.05	300
Kodo millet	158	29050	46270	74107	27837	1.60	175
Barnyard millet	163	29050	46270	106943	60673	2.31	369
Finger millet	124	29050	46270	61987	15717	1.34	125
Pearl millet	163	29050	46270	108935	62664	2.35	382
SEm±	1.10	-	-	7641	7641	0.16	48
CD (p=.005)	3.37	-	-	23401	23402	0.50	147

lower seed yield (1111 kg/ha) and biological yield (3638 kg/ha). Chickpea sown after foxtail millet, Proso millet, Barnyard millet and pearl millet recorded statistically similar yield. Chickpea sown after Kodo millet closely followed by Finger millet recorded significantly higher (31.3%) harvest index, while Brown top millet-chickpea rotation recorded significantly lower (19.3%) harvest index and it was statistically at par with Little millet/Proso millet/Barnyard millet/Pearl millet- Chickpea rotation. Chickpea sown after Pearl millet/Barnyard millet took significantly higher days (163) to mature, while chickpea preceded by Finger millet reported with significantly lower days (124) up to maturity (Table 4). Intensifying the cropping system with legume also increased grain and stover yields. The synergistic cereal-legume association leads to soil-N enrichment by biological-N fixation under legume cultivation and microbial activity in the rhizosphere (Faiz *et al.,* 2022). This might be due to the fact that use of inorganic fertilizer resulted in better growth attributes of the plants (*viz*., plant height, No. of branches plant^{-1}, dry matter production and dry root biomass). The increased availability of nutrients enhanced greater translocation of photosynthates from the source to sink site that resulted in to higher yield contributing characteristics like number of pods plant^{-1} and seed index, which ultimately increased the seed yield (Sodavadiya *et al.,* 2023).

Table 5 illustrated that same amount of total cost (Rs. 46270/ha) and variable cost (Rs. 29050/ha) was incurred for sowing of chickpea in all crop rotations studied as similar inputs and agronomic practices were followed. Chickpea sown after all millets recorded economic returns with B:C more than one. Among all crop rotations, chickpea preceded by Foxtail millet closely followed by Pearl millet/ Barnyard millet-chickpea recorded with significantly higher gross returns (Rs. 112983/ha), net returns (Rs. 66713/ha), B:C (2.44) and per day returns (Rs. 416/day/ha), while chickpea taken after Finger millet closely followed by Kodo millet and Little millet recorded with significantly lower gross returns (Rs. 61987/ha), net returns (Rs. 15717/ha), B:C (1.34) and per day returns (Rs. 125/day/ha). Corroborative findings have also been reported by Meena *et al.* (2021); Bhuva and Detroja (2018).

Table 6 revealed that chickpea sown our different millets recorded same amount of input energy and energy intensiveness as similar package of practices and costs

Table 6: Energy budgeting of chickpea preceded by different millets in Hisar district of Haryana.

Treatments	Input energy (MJ/ha)	Output energy (MJ/ha)	Net energy returns (MJ/ha)	Energy ratio	Energy productivity (Kg/MJ)	Energy profitability (MJ/ha)	Energy intensiveness (MJ/USD)	Specific energy (MJ/kg)	Human energy profitability (MJ/ha)
Foxtail millet	6595	127,092	120,497	19.27	0.31	18.27	19.4	3.17	134.2
Little millet	6595	76,478	69,883	11.59	0.21	10.59	19.4	5.03	80.7
Browntop millet	6595	118,096	111,501	17.90	0.23	16.90	19.4	4.34	124.7
Proso millet	6595	103,042	96,447	15.62	0.26	14.62	19.4	3.84	108.8
Kodo millet	6595	59,022	52,427	8.94	0.20	7.94	19.4	5.21	62.3
Barnyard millet	6595	99,598	93,003	15.10	0.29	14.10	19.4	3.35	105.2
Finger millet	6595	43,707	37,112	6.62	0.16	5.62	19.4	6.01	46.1
Pearl millet	6595	97,379	90,784	14.76	0.30	13.76	19.4	3.29	102.8
SEm±	-	13,265	13,265	2.01	0.02	2.01	-	0.52	14.0
CD (p=.005)	-	40,625	40,625	6.16	0.06	6.16	-	1.60	42.9

Table 7: Effect of millets and nitrogen levels on economics of millet based crop rotation with chickpea.

Treatments	Total duration (days)	Chickpea equivalent yield (Kg/ha)	Variable cost (Rs/ha)	Total cost (Rs/ha)	Gross return (Rs/ha)	Net returns (Rs/ha)	B:C	Per day return (Rs/day/ha)
Foxtail millet-Chickpea	238	2835	52008	96945	155937	58992	1.61	247.8
Little millet-Chickpea	249	1731	52348	97353	98193	840	1.01	3.4
Browntop millet-Chickpea	235	2245	54935	100458	125092	24634	1.24	104.3
Proso millet-Chickpea	231	2154	53830	99133	120333	21200	1.21	91.4
Kodo millet-Chickpea	249	1748	52218	97198	99000	1802	1.02	7.2
Barnyard millet-Chickpea	241	2836	53523	98765	156016	57251	1.58	236.5
Finger millet-Chickpea	240	2459	61573	108423	136271	27848	1.28	115.5
Pearl millet-Chickpea	234	3114	57513	103550	170542	66991	1.65	285.1
SEm±	0.66	168	-	-	8798	8798	0.09	36.1
CD (p=.005)	2.03	515	-	-	26947	26947	0.27	110.4

Table 8: Energy budgeting of milletbased crop rotations with chickpea in Hisar district of Haryana.

Treatments	Input energy (MJ/ha)	Output energy (MJ/ha)	Net energy returns (MJ/ha)	Energy ratio	Energy productivity (Kg/MJ)	Energy profitability (MJ/ha)	Energy intensiveness (MJ/USD)	Specific energy (MJ/kg)	Human energy profitability (MJ/ha)
Foxtail millet-Chickpea	13,354	185,357	172,004	13.88	0.25	12.88	14.00	3.89	96.0
Little millet-Chickpea	13,342	131,658	118,317	9.86	0.16	8.86	14.00	6.32	68.1
Browntop millet-Chickpea	13,324	196,374	183,050	14.73	0.23	13.73	13.40	4.37	101.7
Proso millet-Chickpea	13,542	157,469	143,928	11.62	0.19	10.62	13.90	5.11	81.5
Kodo millet-Chickpea	13,354	112,289	98,936	8.40	0.16	7.40	14.00	6.40	58.1
Barnyard millet-Chickpea	13,354	200,722	187,368	15.03	0.26	14.03	13.70	3.73	103.9
Finger millet-Chickpea	14,016	166,532	152,516	11.88	0.22	10.88	12.90	4.55	86.2
Pearl millet-Chickpea	16,293	228,629	212,336	14.03	0.27	13.03	15.80	3.65	118.4
SEm±	50	14,051	14,051	1.01	0.01	1.01	0.09	0.45	7.2
CD (p=.005)	156	43,033	43,033	3.09	0.04	3.09	0.29	1.40	22.2

were followed. Among all treatments, chickpea sown over foxtail millet closely followed by chickpea taken after brown top millet recorded significantly higher output energy (127092 MJ/ha), net energy returns (120497 MJ/ha), energy ratio (19.27), energy productivity (0.31 kg/MJ), energy profitability (18.27 MJ/ha) and human energy profitability (134.2 MJ/ha), while chickpea sown over finger millet recorded significantly lower energy budget in the form of different energy based indices *i.e.*, output energy (43707 MJ/ha), net energy returns (37112 MJ/ha), energy ratio (6.62), energy productivity (0.16 kg/MJ), energy profitability (5.62 MJ/ha) and human energy profitability (46.1 MJ/ha).

Total crop rotation

Table 7 revealed that among all crop rotations, Little millet/ Kodo millet-Chickpea crop took significantly higher crop duration (249 days), while Proso millet- chickpea rotation recorded with significantly lower crop duration (231 days). Pearl millet- chickpea closely followed by barnyard millet/ foxtail millet-chickpea rotation recorded significantly higher (3114 kg/ha) chickpea equivalent yield, while Little millet-chickpea closely followed by Kodo millet-chickpea rotation recorded significantly lower (1731 kg/ha) chickpea equivalent yield. Chickpea equivalent yield recorded with brown top millet-chickpea and Proso millet-chickpea rotation were statistically at par. Maximum variable cost (Rs. 61573/ha) and total cost (Rs. 1,08423/ha) for cultivation of both crops in rotation was reported with Finger millet-Chickpea rotation, while Foxtail millet-chickpea rotation recorded with minimum cost. All millet based crop rotations with chickpea were proved economically profitable having B:C more than one. Among all crop rotations, pearl millet-Chickpea closely followed by barnyard millet/foxtail millet-Chickpea recorded significantly higher gross returns (Rs. 1,70542/ha), net returns (Rs. 66991/ha), B:C (1.65) and per day returns (Rs. 285.1/day/ha). Little millet-Chickpea crop rotation closely followed by Kodo millet-chickpea rotation reported with significantly lower net returns (Rs.840/ha), B:C (1.01) and per day returns (Rs. 3.4/day/ha). Chickpea is a deep-rooted crop, therefore, which efficiently utilized the soil moisture for realizing higher yields. These results are in close conformity with the findings of Bana *et al.* (2023); Sharmili *et al.* (2023); Mohan *et al.* (2019).

Table 8 illustrated that all crop rotations except pearl millet/finger millet/proso millet followed by chickpea recorded statistically similar input energy. Pearl millet-chickpea rotation recorded significantly higher input energy (16293 MJ/ha), while brown top millet-chickpea rotation found with lower input energy (13324 MJ/ha). Significantly higher output energy (228629 MJ/ha) was recorded with pearl millet-chickpea closely followed by barnyard millet-chickpea rotation, while kodo millet-chickpea rotation recorded minimum output energy (112289 MJ/ha). Among all crop rotations, pearl millet- chickpea closely followed by barnyard millet-chickpea rotation recorded significantly higher net energy returns (212336 MJ/ha), energy productivity (0.27 kg/MJ), energy intensiveness (15.8MJ/USD) and human energy profitability (118.4 MJ/ha), while kodo millet - chickpea rotation recorded significantly lower net energy returns (98936 MJ/ha), energy ratio (8.40), energy productivity (0.16 kg/MJ), energy profitability (7.40 MJ/ha) and human energy profitability (58.1 MJ/ha). These results were in conformity with the findings of Kumar *et al.* (2022) for pearl millet-wheat rotation and Dhaka *et al.* (2017); Choudhary *et al.* (2017).

CONCLUSION

During *Kharif* season among all millets (foxtail millet, little millet, brown top millet, proso millet, kodo millet, barnyard millet, finger millet and pearl millet) tested, Pearl millet was found most suitable, which produced significantly higher grain yield (2462 kg/ha), biological yield (10066 kg/ha), net energy returns (121552 MJ/ha), Energy intensiveness (14.0 MJ/USD), human energy profitability (133.3 MJ/ha) compared to all other millets might be due to it's maximum test weight (6.7 g), plant height (190.5 cm) and lower duration (71 days). Although Finger millet recorded second highest seed yield (1971 kg/ha) and it was most profitable with maximum net returns (Rs. 11975/ha) and B:C (1.19) but it was not fit in rotation with chickpea due to it's long duration (116 days) as it delayed chickpea sowing by 39 days.

In *Rabi* season chickpea sown after Foxtail millet recorded significantly higher seed yield (2080 kg/ha), biological yield (8923 kg/ha), net returns (Rs. 66713/ha), B:C (2.44), net energy returns (120497 MJ/ha), energy ratio (19.27), energy productivity (0.31 kg/MJ), energy profitability (18.27 MJ/ha) and human energy profitability (134.2 MJ/ha) compared to other crop rotations might be due to significantly higher plant height (86.8 cm), branches/plant (11.1), seeds/pod (1.16), pods/plant (122.8) and seed index (15.9 g). Considering economics and chickpea equivalent yield, it is concluded that Little millet/Kodo millet-chickpea rotations are least economical might be due to long *Kharif* crop duration, delayed sowing of *Rabi* crop and less yield obtained.

Thus, it is concluded that pearl millet-chickpea (total duration of 234 days) closely followed by foxtail millet-chickpea rotation recorded with significantly higher chickpea equivalent yield (3114 kg/ha), net returns (Rs. 66991/ha), B:C (1.65), per day returns (Rs. 285.1/day/ha), net energy returns (212336 MJ/ha), energy productivity (0.27 kg/MJ), energy intensiveness (15.80 MJ/USD) and human energy profitability (118.4 MJ/ha) was found most economical and suitable crop rotation for sandy loam areas of Hisar district of Haryana, India.

Conflict of interest

All authors declare that they have no conflicts of interest.

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